ENGINEERING ANALYSIS SUBSYSTEM ENVIRONMENT
FOR SPACECRAFT ENGINEERING SUBSYSTEM
MISSION Operations

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Abstract

Important aspects of mission operations for spacecraft (S/C) sent to explore outer space are: engineering subsystem performance analysis, characterization, and commanding, all involving a substantial amount of human resources and time. Recent efforts have brought about several productivity enhancement measures within the mission operations area that include: the streamlining of the operations process (planning, sequencing, monitoring, analysis) and the development of a multimission operations environment to support automation in analysis.

In previous papers, we reported on the development of an integrated S/C Engineering Analysis Subsystem Environment (EASE) prototype. EASE is a collection of computer programs on networked workstations providing a multimission, multisubsystem, environment that enables the operation of several S/C simultaneously with fewer analysts, Through the use of automated tools, graphical data visualization and information management, EASE has achieved an increase in mission operations productivity. The EASE prototype has been in use for some time in mission operations of the Galileo WC.

Recently, a database, a trending tool, and a power sequence expansion tool have been added to EASE, This paper discusses these enhancements and provides an update of the operation experience with the realtime Galileo telemetry data,

Introduction

We are now entering a new era of spacecraft (S/C) mission operations, The cost of mission operations has become a major driver affecting the affordability of future missions. The nature of missions has also changed. For example, the new class of Discovery missions will embody fewer science payloads and will have much shorter durations as compared to the traditional missions like CASSINI. However, there will be a greater number of smaller spacecraft flying at any given time, thus requiring either multiple ground operations teams or shared teams, Emphasis will be on low cost, and therefore less elaborate, mission operations undertakings,

In all cases, the objective will be to reduce mission operations costs, without causing undue adverse risks to mission performance. This can be achieved by redesigning and streamlining the mission operations process (planning, sequencing, performance monitoring, reviewing, etc.); by utilizing smaller teams; sharing resources between teams or sharing teams between or amongst missions; increasing productivity through automation; the reuse or adaptation of various tools; and developing a reusable multimission operations environment, The objective, of course, is to accomplish all this while continuing to maintain the present high reliability levels.

One aspect of mission operations relates to that of the S/C engineering subsystems. In previous papers (Ref. 1-4) we introduced the concept of the Engineering Analysis Subsystem Environment (EASE) and discussed the EASE prototype. Recently, a database, a trending tool, and a power sequence expansion tool have been added to EASE, This paper discusses these enhancements and provides an update of the operation experience with realtime GLL telemetry data. But first we briefly discuss spacecraft analysis and provide some background information on EASE.

A spacecraft system intended for planetary exploration typically consists of scientific instruments and engineering subsystems, Examples of engineering subsystems are power, attitude and articulation control (AACS), command and data handling, telecommunications, temperature, and propulsion.

As part of mission operations, subsystem analysts establish performance boundaries and monitor the status of each subsystem to ensure that it operates within the boundaries. Judging the performance of the spacecraft is based on how it reacts to its environment as it completes a set of commands sent from the ground, Normally, everything is quite predictable. In addition to monitoring and controlling the WC, subsystem analysts also validate that all is well by observing trends in consumable items such as power and propellant mass, and they routinely report selected performance parameters.

One major aspect of mission operations is monitoring and analyzing downlinked engineering telemetry data which was discussed in earlier papers. Another aspect is formulating uplink commands to the spacecraft. The uplink process requires far greater effort than the downlink. Here extensive planning effort is required to devise sequences for the spacecraft, When devising these sequences, one must

use the S/C resources wisely and ensure that the S/C is not adversely affected.

The present practices in engineering analysis at JPL can be characterized by too much manual work, a lack of sufficient analysis tools, uneven distribution of these tools among subsystems, difficulty in generating predicts, and lack of tight integration and therefore cumbersome interaction among subsystems, All of these elements have made mission operations costly, but at the same time have provided an opportunity to investigate new approaches to mission operations.

One such approach is an integrated environment for engineering analysis called EASE (Engineering Analysis Subsystem Environment). The intention of this environment is to provide a framework within which automation, subsystem interaction, and integration are facilitated,

EASE is a modular multimission architecture and environment for S/C analysis, monitoring, and sequence support It is a collection of computer programs running on high performance computer workstations used for engineering subsystem telemetry monitoring, off-line analysis, sequence review, and selected performance predictions. A graphical user interface is used to provide a friendly environment for the analyst, This interface is useful because it allows analysts who are not necessarily computer experts to easily learn and be able to use the analysis tools, Also, the multimission architecture of EASE allows the analyst to support the operations of several missions or subsystems simultaneously, reducing mission operations costs.

The EASE Environment

EASE provides an environment by which a user (S/C analyst) can invoke software tools and analysis modules to carry out S/C operations analysis. The environment is an open system framework where analysis tools are integrated together, allowing the user to move from task to task without leaving the environment It includes components common to all subsystem analysis:
- Command shell - interpreting user requests,
- Data visualization tools (e.g. plots),
- Data management tools (e.g., DBMS), and
- Trending tools.

The Command Shell

EASE, which runs on a Sun SPARC workstation, currently uses X-windows/Motif as its shell interface. It presents the user with a menu with several sub levels, whereby the individual functions can be exercised concurrently. In order to limit the number of input errors, EASE forces the user to make selections from dialog boxes rather than textual input.

Data Visualization

The output of analysis modules can be more readily interpreted when presented in a graphical format: plots; state transition diagrams; color changes for alarms, rather than in tabular form, etc. EASE provides a graphical user interface, based on the commercial S/W package DataViews, to display the analysis results. DataViews allows easy definition of screens in color and supports plotting of realtime data.It has dynamic alarm capabilities that provide color changes when the incoming data is outside pre-defined threshold values.

EASE feeds all output data from subsystem analysis modules to the display server, The display server brings up DataViews screens and binds realtime data to screen objects for graphical display,

Data Management

The display server itself has no mechanism to save the data passed to it so no history is available. If the user pops down a screen and later pops it back up again, any data previously bound to the screen objects (e.g., graphs) are lost To avoid this a means of saving the processed data, i.e. a database management system, was added to EASE. The database is a commercial database called Metrics. It provides high speed relational database ideal for scientific engineering applications; complete mathematical and statistical libraries; and the ability to graph data in a variety of forms. The link between data and Metrica is achieved by adding the S/W program TPS (Telemetry Processing System) which was originally developed for the Mars Rover project All the subsystem analyzed data, which in the previous versions of EASE was directly routed to the display server, is now directed through the TPS which formats and archives the data to the database. To visualize the latest data in realtime as well as the historical data the display server queries the database through TPS. Metrics provides the Kingfisher interface for the user to administer the database, e.g. define schema, set up graph plot formats, or run SQL-like queries. It also provides a scripting language, TSL, to perform some of the cm-line functions of Kingfisher. With TSL we were able to develop access functions such as reporting on individual channel data, power subsystem status reports, and plotting of the archived data.

Trend Analysis

DBMS also is used to store data for long term trend analysis, A trend is defined as a general course, inclination or direction. Examples of trends in S/C data are degradation of hardware components such as nuclear power sources, Solar Arrays (SA), batteries, gyros, and Traveling Wave Tubes (TWTAs) or drift in the S/C clock, Actions taken onboard S/C will manifest themselves in changes in S/C trends, Correlation of these trends provides valuable insight
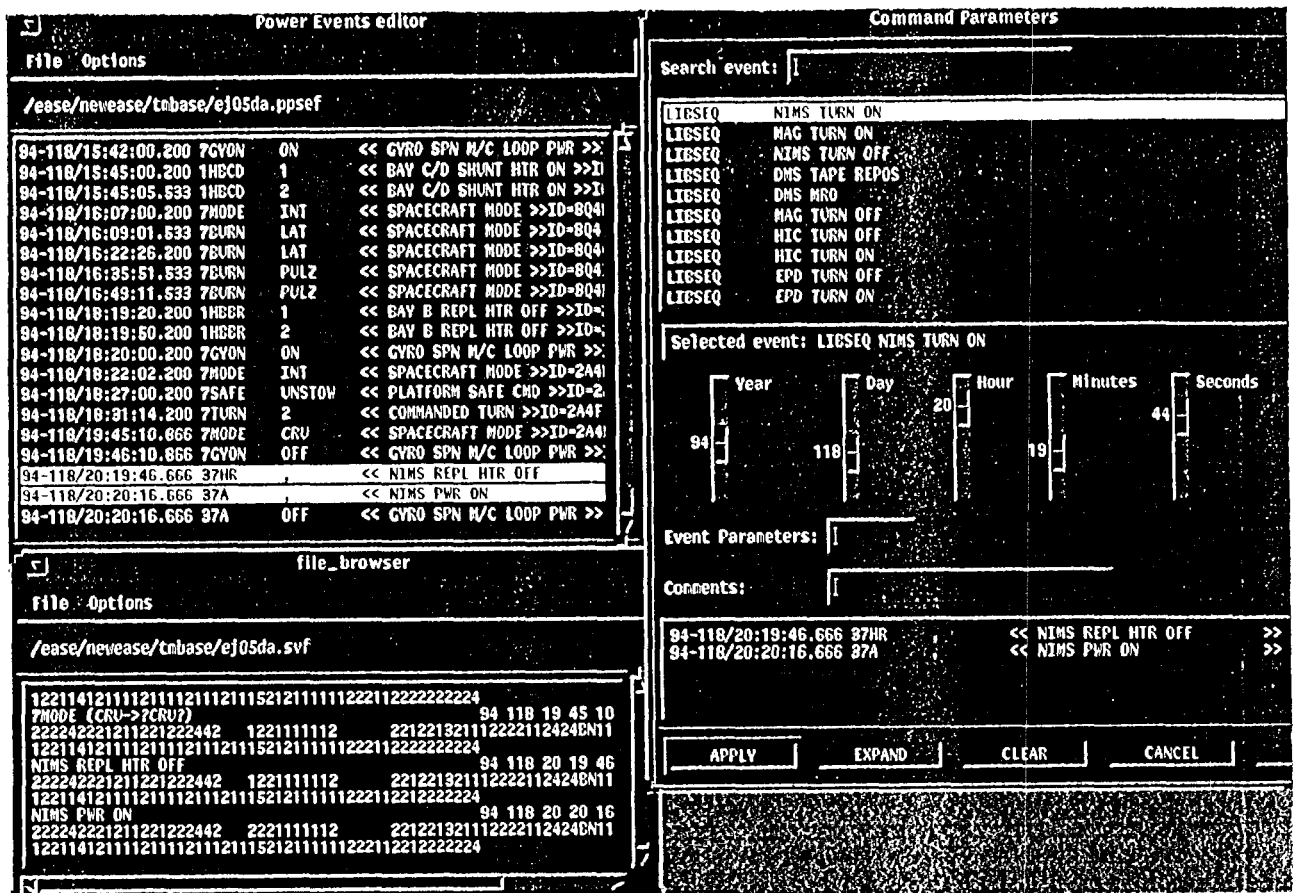
Figure 1, Screen dump of the user interface for the pef-editor

into S/C performance. For example correlation of SA degradation with S/C temperatures and flight paths allows the analyst to predict future available S/C power more accurately.

The trend analysis tool has the following capabilities:

- Mathematical operations such as Fourier transformation, integration, differentiation, smoothing, linear regression, interpolation, etc.

- Sampling of data at required intervals rather than having to use the entire data set,

- Presenting analysis results in various graphical formats (e.g. surface or contour plots,)

Much, but not all, S/C data trending can be done via TSL interface with Metrics, Therefore, the commercial trending tool was augmented by adapting the public domain package XMGR that has an abundant set of statistical functions and graphical plotting capabilities.

Galile0 PPS Sequence Productivity Tools

The Galileo S/C stores in its on-board memory the commands to be executed over time. Most S/C events, such as maneuvers, science instrument control, and data returns depend on the proper execution of these commands, S/C commands are packaged into sequences. A sequence may contain thousands of commands, and may cover a period of anywhere from hours to months, Once created sequences are "uplinked" to the S/C to be executed step-by-step at predetermined times,

Although there is an overall mission plan, the specifics of each sequence must be worked out during the command sequence development process. Inputs are taken from various sources such as mission requirements, scientific instrument requests, and engineering necessities. Through a process of analysis and negotiation a complete and uplink-ready sequence-of-events file (SEF) is constructed.

It is the responsibility of the Galileo Orbiter Engineering Team (OET) to coordinate the uplink sequence generation process. OET ensures that the sequences are complete and incorporate the desired tasks, without exceeding S/C constraints, The Galileo OET is divided into units. Power related items are handled by the Power/Pyro Subsystem (PPS) unit whose analysts track the S/C power

availability, consumption, and pyro-actuation events,

One of the primary tasks of the Galileo PPS analysts is to create power profile projections for sequences under development. As the total power required by the loads on the S/C can easily exceed the available power, it is vital to anticipate the power states of the S/C throughout the entire uplink process. Furthermore, it is helpful to identify as early as possible those sequences that contain problems with power usage so changes maybe effected with the least impact,

Present Practice

The power profiles themselves are produced by a FORTRAN program called GPWR (Galileo PoWeR) that runs on a Unisys 1100B computer. GPWR takes as input a file which contains information about the power loads on the Galileo S/C (Power Load Coding Table), and a time-ordered file of vectors describing the state of each load on the S/C (State Vector File (SVF)). SVF file contains a list of 121 single digit numerical entries (for example 222121111261121,, 118...,) corresponding to power usage levels defined in the power load coding table.

During the later phases of the sequence development process, when an SEF is available, an SVF can be generated directly using a program called RSEF (Read-SEF). This program, written in Unisys Macro Language, suffers from a number of defects, The code must be edited before running to define the initial spacecraft states, Worse, some power related events are missed and must be manually inserted after running,

One part of the EASE productivity enhancement task was to implement a new, workstation-based version of RSEF that flags all power related commands, and produces a complete state vector file for input to GPWR.

When an SEF is not available, as is the case in the early part of the sequencing process, the PPS analysts must manually generate the SVF. Here, a sequence is described only in general terms. For instance no more information than the date and time of a maneuver maybe available with the specifics to be supplied later. Nevertheless, the PPS analysts are called upon to provide a power profile prediction. Even without exact details an experienced PPS analyst can produce a good estimate of the power usage for a given sequence. But this requires the manual construction of a SVF which is a cumbersome process, Also the file is extremely difficult to edit by hand. In fact a large portion of the PPS analyst's time is spent constructing and modifying this file.

New Tools

An editing tool has been developed that allows the analyst to construct an SVF by making selections from a pre-define library of command sets rather than having to manually type each command, By pointing and clicking the analysts assembles a collection of power events to create a Power Events File (PEF). RSEF reads the PEF and

generates the corresponding state vector file for GPWR. Fig. 1 depicts a screen dump of the user interface for the editor.

The tool is called pef_editor. It supports the definition and expansion of library sequences into power events. A library sequence is a pre-defined set of events that are associated with an activity. For example turning on the Near Infrared Mapping Spectrometer (NIMS), involves 2 events: turn off the NIMS replacement heater and after 1.5 minutes turn on the NIMS itself. These 2 events are now combined into one library sequence "NIMS-TURN-ON" via the editor. When the analyst selects the library sequence "NIMS TURN ON' to incorporate into sequence of power events, the editor automatically expands the library sequence into the 2 events with the correct absolute time values. See Figure 1.

Galileo Operation Experience Update

The EASE prototype has been operational in the Galileo Mission Support Area (GLL-MSA) using realtime Galileo telemetry data and is being used by the power analysts, Two examples of its recent use are included here:

GLL Power Plots

Figure 2 is an example of the Galileo PPS performance report generated by EASE. It shows a summary of power generated by the nuclear powered source, power consumed by do and ac loads. It also shows the history of several S/C bus or load currents and voltages of interest.

GLL Dual Drive Actuator Pulsing

As the Galileo OET attempted to fully open the WC'S partially deployed HGA, the original ground system did not have the capability to provide the necessary information fast enough to support the commanding schedule, The original capabilities consisted of channelized line printer output and access to data from tape storage. Both were too slow, Also the data was presented in terms of Earth Receive Time (ERT) with adjacent data points having the same time stamp. This made the interpretation of the data difficult.

The situation was remedied by using the EASE prototype and the new S/W which was developed and added to EASE, EASE simply parsed the telemetry to provide the correct time stamp for each data point, While EASE still received data from the line printer, the variable packet blocks could be printed without over driving the printers. In this way EASE provided near realtime plots of power subsystem data that was indicative of the ball screw rotation driving to open the HGA. Plots of this data were provided within minutes and aided analysts to determine if the ball screw had rotated and ascertain if the commanding strategy was successful, Figure 3 shows an example of a plot generated in the way, The figure shows the S/C shunt

Galileo Power Distribution

Galileo PPS Performance Report
Period of Acquisition: 93-243/12:00 to 93-252/12:00
Submitted by: Steven C. Mikes

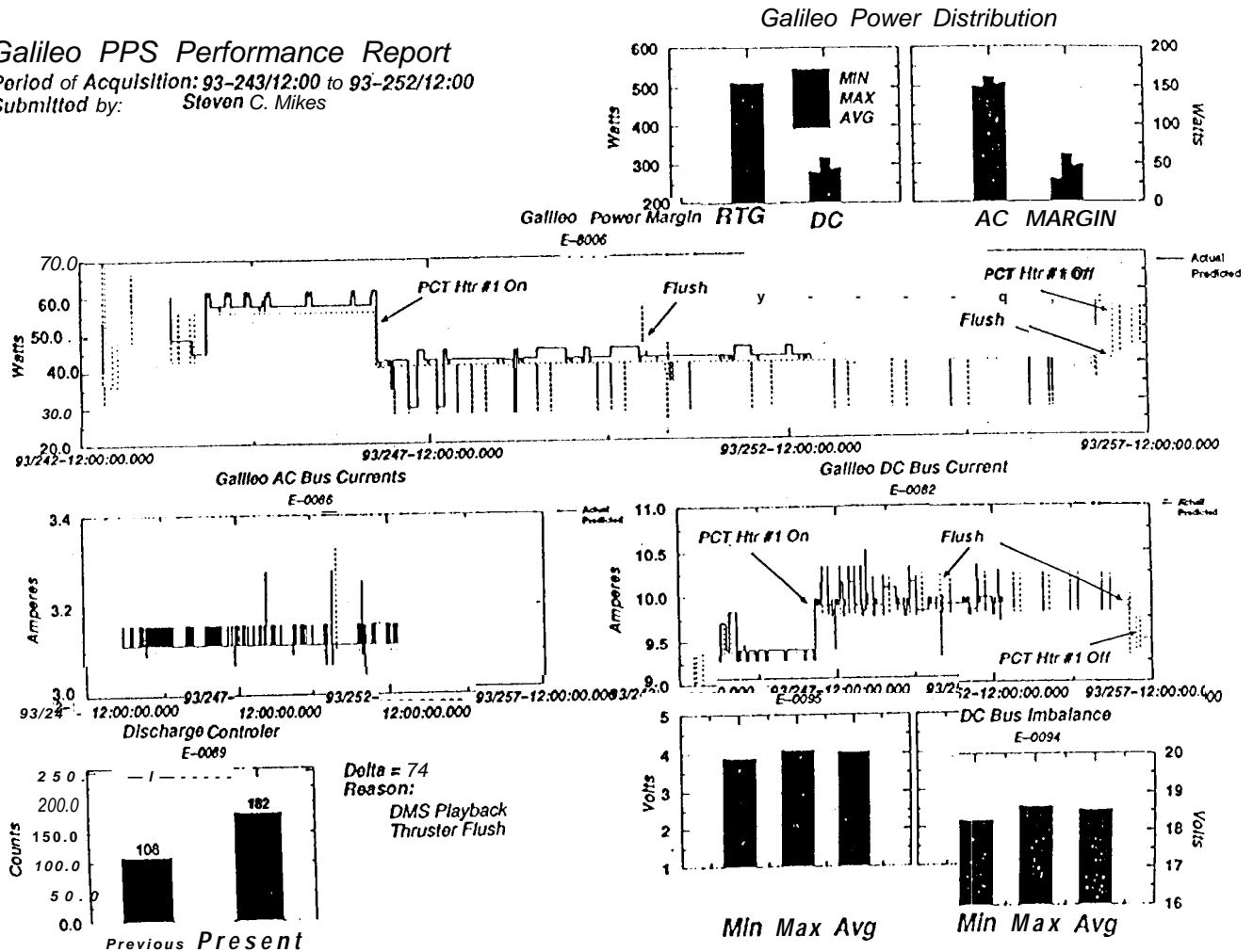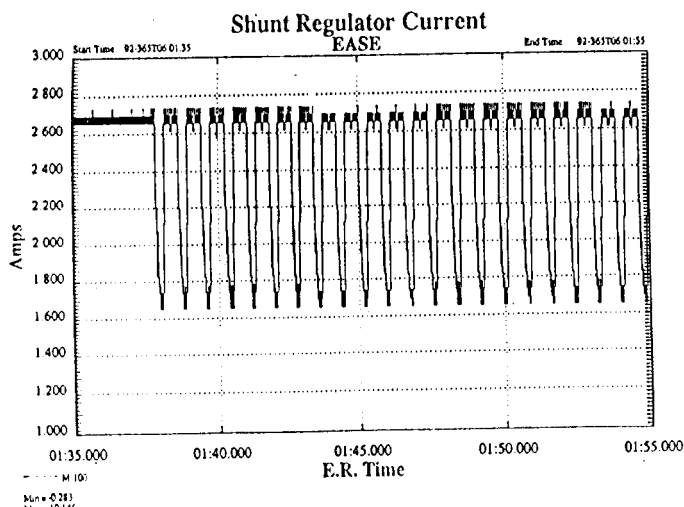Figure 2. Example of a Galilee PPS performance report generated by EASE

Figure 3. Dual Drive Actuator Pulsing

regulator power (i.e. excess power) as a function of time, which in this case related to the HGA actuator motor current and therefore the movement of the ball screw.

EASE also provided a means to enter the period of the pulses sent to Galileo and present a graph of each individual pulse, The pulses were rapidly displayed, thus providing a 'movie' effect to the analysts, Credit for this idea is due to one of the GLL temperature subsystem analysts. Had there been a gradual change in the shape of the graph, it would have been clearly spotted as a trend indicating potential success.

Conclusion

Over the past two years several new tools have been added to the EASE prototype. A new, UNIX workstation-based SEF reader (RSEF) has been added which has greatly increased the productivity of Galileo's PPS Analyst. The new

RSEF has the capability to model the attitude and articulation subsystem (AACS) excursions. It models the DMS (tape recorders), the scientific instruments, and the scientific instrument heaters with greater fidelity,

Another new S/W tool added is the PEF-editor. This tool which has a graphical interface, enables the PPS analyst to easily construct an SVF from the PPS events without having to manually type the associated commands. The analyst simply selects and assembles commands from a pre-defined library of commands, The tool has enabled the power analysts to handle their increased workload with reduced staffing.

Other capabilities developed include: archiving and retrieval of telemetry data or analysis results; trend analysis; and advanced plotting. PPS analysts now can automatically generate the routine power reports or compile the trend analysis reports. Generating these reports was previously extremely labor intensive.

The introduction of productivity enhancement tools in mission operations has dramatically increased the productivity of the power analysts. It is expected that the EASE evolution will provide additional productivity gains as the emphasis on mission operations improvement becomes more formal,

Acknowledgments

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